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RESPONSE EFFECTS UPON THE

PSYCHOLOGICAL REFRACTORY PERIOD

A THESIS

Presented to

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PSYCHOLOGICAL REFRACTORY PERIOD

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SUMMARY

The psychological refractory period is defined as the increased response latency to the second of two discrete stimuli as the interstimulus interval is decreased below 300 msec. The present study was primarily concerned with investigating the effects upon response latency as a function of stimulus interference with a formed, but not emitted, response. The results indicated that increased response refractoriness could be induced as the interval between the stimulus and the response formation was reduced. Concurrently, the study also replicated previous findings using the paradigms of two successive stimuli and two responses, two successive stimuli and a response to the second stimulus, and response to a stimulus whose arrival was related to response emission. Finally, areas of further research suggested by the study were noted.

CHAPTER I

INTRODUCTION OF THE PROBLEM

The psychological refractory period has been operationally defined as that interval between two discrete stimuli wherein the response latency to the second stimulus is atypically increased. Refractoriness has been noted in various studies when the temporal interval between stimuli was decreased below 500 milliseconds. The determination of the locus of refractoriness in the stimulus-response sequence provided the setting for the research problem. Particularly, the study dealt with the phenomenon of refractoriness as a central neural process.

A study by Davis (1965a), on the expectancy hypothesis of refractoriness, attempted to show the psychological refractory period to be independent of the response in that the critical factor was attention to a stimulus rather than to the making of a peripheral response. This study, which culminated a series of research studies on the psychological refractory period, failed to consider adequately the effect of the response. The Davis studies (1956, 1957, 1959, 1962, 1965a), although presenting important evidence for the single channel theory of refractoriness, considered only the sensory input side of the human information processing mechanism.

It was with the response side of the human processing channel that the present research was concerned. Specifically, it was hypothesized the refractoriness in response latency would result when stimulus interference with the formed, but not emitted, response could be induced. The specific condition tested was one where subjects were required to emit a response with one hand and to respond to a stimulus with the other hand. In all instances it was required that an emitted response precede the elicited response.

Thus, if the stimulus eliciting a response were presented prior to the emitted response, increased latency of the elicited response would provide evidence of interference. It was further hypothesized that stimulus presentation earlier in the response formation sequence could increase the latency of the elicited response.

CHAPTER II

REVIEW OF PREVIOUS RESEARCH

The concept of neural refractoriness as an issue in the control of behavior and psychological functioning was proposed by Dodge (1926). Thorndike (1927) and Dodge (1927) further amplified this concept to form the rudiments of a theory of central refractoriness of behavior. This view postulates that following a response there is a period of time in which the human system is refractory to further stimulation. Telford (1931) utilized variable interstimulus intervals in the first experiments designed to test the theory of central refractoriness. He attributed his finding to the existence of a "psychological refractory period" which was thought to be a manifestation of the refractoriness of the neural processes underlying it.

This term has been used to characterize the increased latency in reaction time to the second of two stimuli presented at short interstimulus intervals. The analogy to neural refractoriness is somewhat strained since the central processes do accept stimulus inputs during this period. However, the mechanisms may store the inputs for future action.

Since the phenomenon is intimately related to human sensory-motor performance, interest was revived in the refractory period by the work of Craik (1947, 1948) on control system performance. Since then study in the area has been quite extensive. Analytical surveys of experiments in the field can be found in various reviews (Adams, 1964; Bertelson, 1966; Gottsdanker and Senders, 1959; Reynolds, 1964; Smith, 1967; Welford, 1952, 1960).

The process has been studied using both continuous tracking tasks (Hick, 1948; Vince, 1948, 1949) and intermittent discrete responses. The latter has most commonly utilized a two stimulus presentation and a two choice response apparatus. The responses were usually made on telegraph keys and a subject had only to depress or release a key to record his response. This technique controlled for movement time and equated responses across subjects. It was recognized quite early in the study of the refractory period, regardless of the theory held, that the determining factors were of a central nature, thus there has been a tendency to minimize peripheral responses.

Theoretical Orientations

Smith (1967) has indicated that the main theoretical orientations for the study of the psychological refractory period are: central refractoriness, preparatory state, and single channel theories.

The central refractoriness theory is derived from the physiological concept of neural refractoriness as indicated above. The position is especially weak since the delay in the second reaction time is based entirely upon a fixed refractory period. The refractory period is held to be a temporal constant independent of the specific conditions. The studies on foreperiod (Drazin, 1961; Foley, 1959; Kay and Weiss, 1961; Klemmer, 1957) all indicate that the reaction time is highly influenced by uncertainty as to the duration of the foreperiod.

The preparatory state theories may be divided into expectancy theories and readiness theories. The expectancy theory is based upon a study by Mowrer (1940), in which it was shown that subjects trained to a high degree of expectancy for a certain temporal stimulus interval showed increases in reaction time as a function of the deviation of stimulus application from the subjects' expectancies. This theory has received some support for its prediction that experience with short interstimulus intervals will decrease latency of response (Adams, 1962; Elithorn, 1961; Elithorn and Lawrence, 1955), but these decreases occurred at all intervals with experience. Thus, the short interstimulus intervals still produced the greatest response latencies. The expectancy theory also predicts that with the subject's awareness of the interstimulus interval, i.e., minimum temporal uncertainty, there would be no refractoriness in response. This prediction has not been supported by further studies in which the subjects either received trials with fixed interstimulus intervals (Creamer, 1963) or in which the intervals were based upon response completion (Davis, 1965a). Interstimulus interval variability can influence response latency (Nickerson 1965a, 1965b) but does not appear to provide a complete explanation of sensory-motor performance.

An alternative approach to preparedness is provided by the readiness theory of Poulton (1950). This theory holds that the subject requires a certain period in which to prepare himself to react even with no event or temporal uncertainty. This finding is also supported by the results of Kay and Weiss (1961), Leonard (1958, 1959) and

Nickerson (1965b).

The single channel hypothesis stems from information theory and relates to the concept of the individual having a finite capacity for processing sensory data. Reaction time has been shown to be related to channel capacity (Saltzman and Garner, 1948) and therefore has been utilized as the dependent variable in most studies of the phenomenon.

One approach deals with delays due to perceptual processing. The impetus for this view stems from the work of Broadbent (1958) on stimulus presentations in more than one sense madality. The theory predicts that no delays would be found using different modalities for the stimuli (Smith, 1967). This prediction has not been supported by the available data (Borger, 1963; Davis, 1957; Hirsch and Sherrick, 1961; Warrick, 1961) as the usual latencies in response were found using both an auditory and a visual stimulus. These studies suggest that the critical factors are not a function of the sensory processes themselves.

Alternative single channel hypotheses emphasize the response side of the processing mechanism. One view states that when two responses are to be made in rapid succession, the second is stored until the first has been executed thus conceiving the human to be a single channel operator (Smith, 1967). Extensive theoretical and experimental support has been found for this argument (Craik, 1947, 1948; Davis, 1956, 1957, 1959, 1962, 1965; Fraisse, 1957; Hick, 1948, 1949; Vince, 1948; Warrick, 1961; Welford, 1952, 1959).

It has been observed, however, that when the subject is required to attend to two discrete stimuli, but to respond only to the second of a successive pair, refractoriness in performance is still observed (Davis, 1959; Fraisse, 1957). These results have not been unequivocal (Borger, 1963; Rubenstein, 1964) and there is a suggestion that the factor of attention may be critical in inducing response latency. A simple response selection model would predict no delays, since if no response is required there need be no response selection. Typically, the delays found in the single response case have been shorter than those found under the two response conditions.

One area of disagreement between expectancy theorists and intermittency theorists, or those concerned with the distribution of interstimulus intervals versus those concerned with stimulus attention (Davis, 1965), is the principle of grouping. Welford (1959) has argued that when two signals arrive in close proximity, response will either be delayed or response may be made to the stimuli as a group. This may also occur if the signal arrives close to the beginning of the formation of a response. These results have not been accepted by the expectancy theorists who hold that delays are not unavoidable even in the absence of grouping (Elithorn, 1961; Elithorn and Lawrence, 1955; Halliday, Kerr and Elithorn, 1960; Kerr, Mingay and Elithorn, 1965; Leonard, 1958). The rationale for this position is that with increased practice the second reaction becomes reflexive.

Complex choice reaction times have been studied (Marill, 1957; Elithorn, 1961; Elithorn and Lawrence, 1955; Halliday, Kerr and Elithorn, 1960; Kerr, Mingay and Elithorn, 1963, 1965), but the findings have not been clearcut, since the case is one of both simple and choice reactions. The area is very important because of its application to problems in the area of human performance.

Another theoretical interpretation of the psychological refractory period deals with response competition (Smith, 1967). The second of the two successive, similar responses is more likely to be delayed than when the successive responses are qualitatively different according to this orientation. This viewpoint, although suggestive, has not been experimentally investigated.

One final topic concerns the theory of the psychological refractory period as developed by Welford (1952, 1959) and as modified by Davis (1956, 1957, 1962). This theory attempts to explain response latency in terms of "normal" reaction times. The difficulty with this approach has been explaining the refractoriness found when the interstimulus interval exceeds the first reaction time. Welford (1952) hypothesized that the proprioceptive feedback occupied the channel in a fashion analogous to an external stimulus. This problem also has not been sufficiently investigated.

Thus, from this theoretical framework was developed the problem of response interference with which we were concerned in the present study. Specifically, the study attempted to determine the locus of the psychological refractory period in terms of a single channel hypothesis. Stimulus interference with response emission was hypothesized to be facilitated by response competition, since identical motions were required of the subject. Attention without responding versus simple responding was considered as a subsidiary problem.

CHAPTER III

INSTRUMENTATION AND EQUIPMENT

Control Instrumentation

The apparatus was automated in order to present a standardized experimental environment. The units, which are available commercially, consisted of: a Hunter Model 1245 interval cycler, two Hunter Model 120A Klockounters, a Stoetling electric clock, a Scientific Prototype 26 volt, D.C. power supply, 4027-JM, and assorted Scientific Prototype logic modules (one memory AND gate, 4017-J, one OR gate, 4002-J, and four Flip-Flops, 4019-J).

The equipment was interconnected and wired as is indicated in Figure 3 (see Appendix A) and provided an arrangement allowing presentation of two discrete, successive stimuli and the recording of reaction times of the appropriate responses. To present alternative experimental paradigms simple modifications of this wiring configuration were necessary. These modifications are described in Table 7 (see Appendix A).

The intertrial and the interstimulus intervals were preset on the interval cycler. The electric clock was wired in conjunction with the open phase of the cycle and was used to time the intertrial interval. The clock enabled the accurate presentation of the verbal "ready" signal insuring a uniform foreperiod. The reaction times associated with the responses of the subjects were recorded on the two Klockounters. The experimenter initiated the automated sequence by pressing a control key at a standard time during the intertrial interval. All of the control instrumentation was mounted in a mobile, relay rack for compactness and ease of operation.

Subject Stimulus and Response Apparatus

The subjects were seated before the unit indicated in Figure 4 (see Appendix A). The visual stimuli were presented by two incandescent light bulbs (General Electric, 1815) mounted in 28-volt fixtures with clear plastic covers. Power was provided by a 26-volt power supply.

The subjects responded by depressing telegraph keys upon which their fingers rested. The keys were spring loaded but the force required to depress them was minimal. Also, the subjects were given an opportunity to depress the keys prior to the actual experiment, so that the resistance of the keys was not considered to be a differential factor in the results.

The apparatus included a fixation point, where the subjects were required to look prior to the stimulus presentation under those conditions where two stimuli were to be presented.

The interconnection of the stimulus-response unit with the control instrumentation is indicated in Figure 3.

CHAPTER IV

PROCEDURE AND METHODOLOGY

Selection and Preparation of Subjects

The subjects consisted of 40, right-handed, male students enrolled in general psychology at the Georgia Institute of Technology. The subjects were all volunteers and were rewarded for their participation in terms of classroom credit. The subjects were assigned to one of four experimental treatment groups using a table of random numbers (Winer, 1962).

The experimental groups were of two types. One type involved the traditional approach with two discrete stimulus presentations while the other type utilized emitted responses and a single discrete stimulus. The former type was differentiated into a two response group (I) and a single response group (II). The latter paradigm was divided into a group in which the critical interval was independent of the emitted response (III) and a group in which the critical interval was based upon the emitted response (IV). For all four groups the dependent variable was the same: the right-hand response time.

The general instructions were the same for all subjects (see Appendix B) and preceded the practice session. Additional instructions were group specific, but differed only with regard to the respective independent variables (see Appendices C, D, E, and F) and were given following the practice session.

Each subject was permitted to ask questions during the reading of the instructions and the practice trials. However, questions dealing with other than their specific tasks were deferred until the end of the experimental session, e.g., questions about the purpose of the experiment or the operation of the control equipment.

Experimental Procedure

The procedure for each subject consisted of administering a practice session and then a test session of two parts of equal length.

The subjects were initially given the general instructions, which included the instructions for the simple reaction time trials. These practice trials were ten in number and consisted of five for the left hand and five for the right. Basically, the subject was faced with two response keys and two stimulus lights and was required to press a key when a light was turned on. These trials served a twofold purpose. They acquainted the subject with the stimulus-response unit and his task. In addition, they served to stabilize his normal reaction time and to give a performance baseline.

Following the practice trials and while the necessary modifications in the instrumentation wiring were being made, the subject was given the specific instructions for the test trials. After this point, no questions of any kind were entertained. The test trials began with two familiarization trials, using an interval of 250 milliseconds (msec), which were not recorded and which acted to clarify the specific task for the subject.

Forty test trials were administered in two groups of 20 trials each. There was a five-minute pause between the two groups of test trials in order to give the subjects an opportunity to rest. As subjects became tired there was a tendency for them not to pay close attention, although this did not appear to be of sufficient magnitude to warrant correction.

The trials differed in terms of the critical interval between events. For the two stimulus presentation situation this critical interval was in fact an interstimulus interval. However, for the emitted response groups the interval was based upon the response time, either actual or hypothetical. The intervals used in the experiment were: 050, 100, 150, 200, 250, 300, 350, 400, 450, and 500 msec. Four intervals of each duration were administered to each subject, making 40 trials in all. The order of presentation was determined by a table of random numbers (Winer, 1962).

Each trial was initiated by the experimenter saying the word "ready," approximately 500 $\pm$ 100 msec prior to the first event. This time was selected following a pilot study, as will be explained later in the chapter. In conjunction with the first event (the beginning of the critical interval) the electric clock was reset. This clock was used to approximate the intertrial interval, which was set at 30 seconds.

Following the subjects' response, the experimenter recorded the relevant times on the Klockounters and reset them; changed the interval on Channel A of the interval cycler; and depressed the control key. This last action prepared the apparatus to present the next trial automatically.

Following the 40 test trials, the subjects were informed of the purpose of the experiment and given an indication of their performance. Finally, they were requested not to disclose the nature of the experiment to their classmates.

Pilot Study

Ten subjects were given the free emitted response conditions prior to the basic experiment. The primary aim of this study was to get an indication of the time the "normal" subject waited after the ready signal before emitting a response. The results indicated that the mean delay time was 650 msecs. This value was used for two purposes in the formal study. First, it was used to set the approximate foreperiod, the time between the alerting signal and the first stimulus event. Second, it was used to determine the hypothetical baseline from which to measure the critical interval in the forced response case.

Since much has been written about the effects of foreperiod, foreperiod variability, and reaction time (Drazin, 1961; Foley, 1959; Klemmer, 1956, 1957; Teichner, 1957), it was considered important to standardize the foreperiods between trials and between subjects. This was accomplished by the experimenter giving the verbal "ready" signal when the electric clock indicated the approximately 500 msec remained prior to the first event. This method was found to be accurate within ± 100 msec. The times used were considered within the optimum range for preparation for a response (Leonard, 1958; Poulton, 1950). What slight variability there was between foreperiods was not considered to be a confounding factor (Klemmer, 1956). This foreperiod length also permitted standardization among all experimental conditions.

Experimental Methodology

The experiment was conducted in a combined design using four groups; however, in terms of analysis there were two separate experiments. Three of the four groups consisted of replications of previous studies and were included primarily for control purposes.

The design utilized only right-handed subjects. This decision was based upon the desire for the maximum automation possible with the available facilities and to exert more adequate control. In the emitted response condition, it was felt that to indicate the initial response on each trial would both bias and confuse the subject. However, in conjunction with this decision, it was necessary to run the traditional psychological refractory period experimental groups to ensure that the phenomenon had not been removed by this technique. Thus, the two stimulus groups were run under exactly the same conditions as the response groups, in terms of intervals used, direction of stimulus presentation (left to right only), and type of ready signal employed. These conditions are shown in (a) and (b) in Figure 5 (see Appendix G).

A verbal "ready" signal was used in the experiment because it was desired that the subjects give an emitted response, in the response based conditions, rather than a stimulus elicited one. Thus, an alerting signal was employed that was totally different from the stimulus to which the subjects were required to react. Also, it was desired to provide a rather specific point in time at which it could be presumed that the subjects would begin to prepare their responses (Arnett, 1966; Karlin, 1965).

The conditions for the response based groups are shown in Figure 6(a) and (b). The freely emitted response group is a replication of a study by Davis (1965) in which the critical interval is based upon the completion of the first response. The forced response group utilizes the normal emission time of 650 msec derived from the pilot study as a baseline. From this baseline the presentation time of the visual stimulus is measured in both directions. The subject is instructed that the left-hand response must always precede the right-hand response. The purpose of this arrangement is to present a stimulus at the point where a response is being formed, but has not yet been emitted.

To repeat, the dependent variables are right-hand reaction time in all conditions. For the stimulus groups, the independent variables are the interstimulus interval and whether the subject is required to make one reactive response or two. For the response groups, the independent variables are the critical interval and relation of the interval to the initial response (independent versus dependent).

CHAPTER V

DISCUSSION OF RESULTS

The data were analyzed by means of a two-way analysis of variance, with repeated measures on one factor (Winer, 1962). The treatment groups were divided into two parts for analysis because the task required of the emitted response groups differed both quantitatively and qualitatively from the groups whose response was elicited.

Results of the Two Stimulus Configuration

The data from both the two response and the one response groups were first tested for homogeneity of variance. Since it was not possible to reject the null hypothesis of homogeneity of variance, the data were analyzed according to the model and the results are shown in Table 1 which appears on the following page. The only significant finding ($P < 0.01$) was that reaction time was related to interstimulus interval. No significant difference was found between the groups where the subjects were required to make reactive responses to two stimuli versus the case where attention to the first stimulus and reaction to the second stimulus was required.

Table 1. Summary of the Two-Way Analysis of Variance, Response Mode versus Interstimulus Interval, for the Presentation of Two Discrete Visual Stimuli

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
BETWEEN SUBJECTS	0.144	19			
Response Mode (A)	0.024	1	0.024	3.43	
Error (Between)	0.120	18	0.007		
	$F_{.95}(1,18)=4.41$				
WITHIN SUBJECTS	0.540	180			
Interstimulus Interval (B)	0.358	9	0.0398	36.18**	< .01
Interaction (AB)	0.009	9	0.001		
Error (Within)	0.173	162	0.0011		
	$F_{.99}(9,162)=2.53$				

The two curves are shown graphically in Figure 1. Two interesting aspects of the data are illustrated by these curves. One is the fact that for each interval the one stimulus group reaction latency exceeds that of the two stimulus group. This is contrary to previous findings (Davis, 1959; Fraisse, 1957, 1957; Kay and Weiss, 1961; Nickerson, 1965b) in studies of attention and the psychological refractory period. A variation in the present procedure is that each subject had maximum event certainty and also temporal certainty with regard to the onset of the first stimulus.

The second suggestive finding illustrated by the graph of the data in Figure 1 is the increase in the curve at an interstimulus interval of 250 msecs. Although this increase is not significant, it does have theoretical implications which will be discussed in the following chapter.

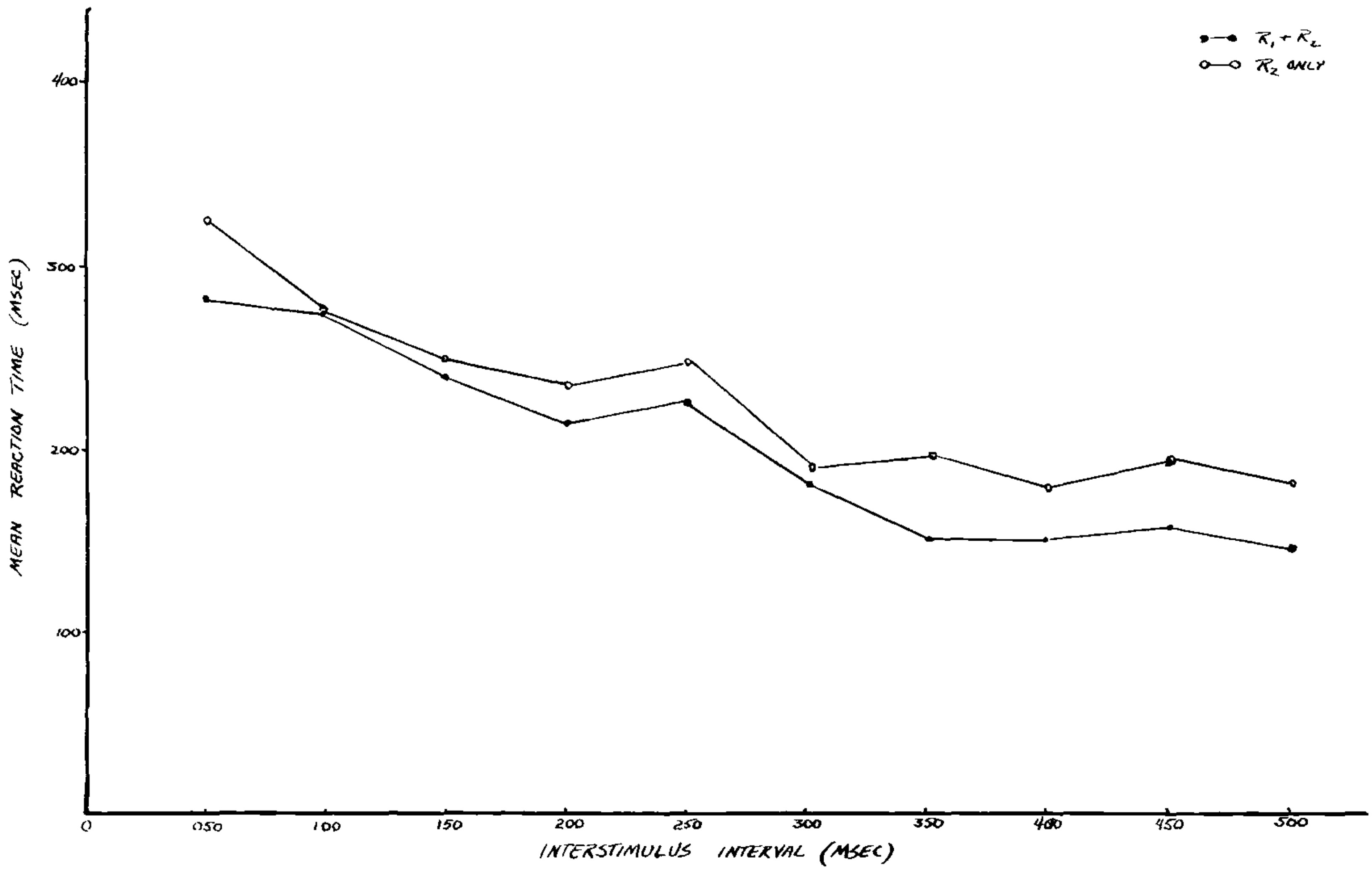


Figure 1. Mean Reaction Time as a Function of Interstimulus Interval

The two groups were combined since they were not significantly different and the interstimulus intervals were analyzed individually, using the Newman-Keuls procedure (Winer, 1962). The results of this analysis are shown in Table 2.

Table 2. Summary of the Newman-Keuls Mean by Mean Comparison for the Combined Mean Reaction Times of the Two Discrete Stimuli Conditions

ISI	500	400	350	450	300	200	150	250	100	050
Mean RT	178	178	184	186	195	233	245	247	273	300
500	–					*	*	*	*	*
400		–				*	*	*	*	*
350			–			*	*	*	*	*
450				–		*	*	*	*	*
300					–	*	*	*	*	*
200						–			*	*
150							–		*	*
250								–	*	*
100									–	*

(* -- Significance at $P < 0.05$)

No refractoriness in response was found at interstimulus intervals in excess of 250 msec. This finding is consistent with previous studies (Davis, 1956, 1959). Although the 150-250 msec intervals showed an increase in reaction latency, they did not differ from one another. However, this effect is confounded by the increase in reaction time for the 250 msec interval noted above.

Results of the Response Based Configuration

The data from the groups in which the relation of the response to the critical interval was an independent variable were first analyzed for homogeneity of variance. There was found to be a significant departure from homogeneity. However, in light of the relative robustness of the F test (Box, 1953) and the high degree of homogeneity in one of the two treatment groups, the analysis was conducted without a data transformation. However, a high level of α was employed ($\alpha = 0.01$) and a very conservative test employed to minimize the possible of Type I error.

The summary of the data analysis is shown in Table 3.

Table 3. Summary of the Two-Way Analysis of Variance, Response Mode versus Critical Interval, for the Presentation of a Single Stimulus

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P
BETWEEN SUBJECTS	1.900	19			
Response Mode (A)	0.378	1	0.378		
Error (Between)	1.522	18	0.085		
WITHIN SUBJECTS	0.501	180			
Critical Interval (B)	0.208	9	0.023		
Interaction (AB)	0.177	9	0.020	28.57**	< .01
Error Within	0.116	162	0.0007		
	$F_{.99}(1,18)=8.29$ (Conservative Test)				

The finding of a significant interaction between the response and the critical interval necessitated an analysis in terms of simple main effects (Winer, 1962; Box, 1954). Due to the existence of heterogeneity of variance, an extremely conservative test was employed.

The results of the analysis of the between group effects for each critical interval are shown in Table 4.

Table 4. Summary of the Analysis of Variance for the Simple Main Effects, Difference Between Response Modes for each Critical Interval

Source	Sum of Squares	df	Mean Square	F	P
050	0.160	1	0.160	17.78**	< 0.01
100	0.131	1	0.131	14.56**	< 0.01
150	0.100	1	0.100	11.11**	< 0.01
200	0.087	1	0.087	9.67	
250	0.038	1	0.038	4.22	
300	0.020	1	0.020	2.22	
350	0.015	1	0.015	1.67	
400	0.004	1	0.004		
450	0	1			
500	0	1			
Within Cell	1.648	180	0.009		

$F_{.99}(1,9) = 10.6$

Significant differences were found for the 050, 100, and 150 msec intervals. The two groups were then analyzed for the effects of interval trend for each treatment condition. The results shown in Table 5 were highly significant for the forced response group, but not all significant for the free response group.

Table 5. Summary of the Analysis of Variance of Simple Main Effects, Difference Between Intervals for each Response Mode

Source	Sum of Squares	df	Mean Square	F	P
Forced Response	0.383	9	0.043	61.43**	< 0.01
Free Response	0.002	9	0.0002		
Within Subjects	0.116	162	0.0007		
	$F_{.99}(1,9) = 10.6$				

The differences in trend are shown graphically in Figure 2 on the following page. The group which was forced to emit a response contingent with a stimulus presentation exhibited the traditional refractory period. However, the group in which the completion of a response determined the stimulus presentation showed no response latency in reaction. This result was consistent with the findings of Davis (1965).

The forced response group was analyzed in a mean by mean comparison using the Newman-Keuls technique (Winer, 1962) and the results are as indicated in Table 6, which appears on page 25. In this case, refractoriness in response was found until the critical interval exceeded 350 msec. This time is similar to that found by Vince (1948, 1949) and Hick (1949) in continuous tracking tasks. No difference was found between critical intervals of 50 and 100 msec or between critical intervals of 150 or 200 msec.

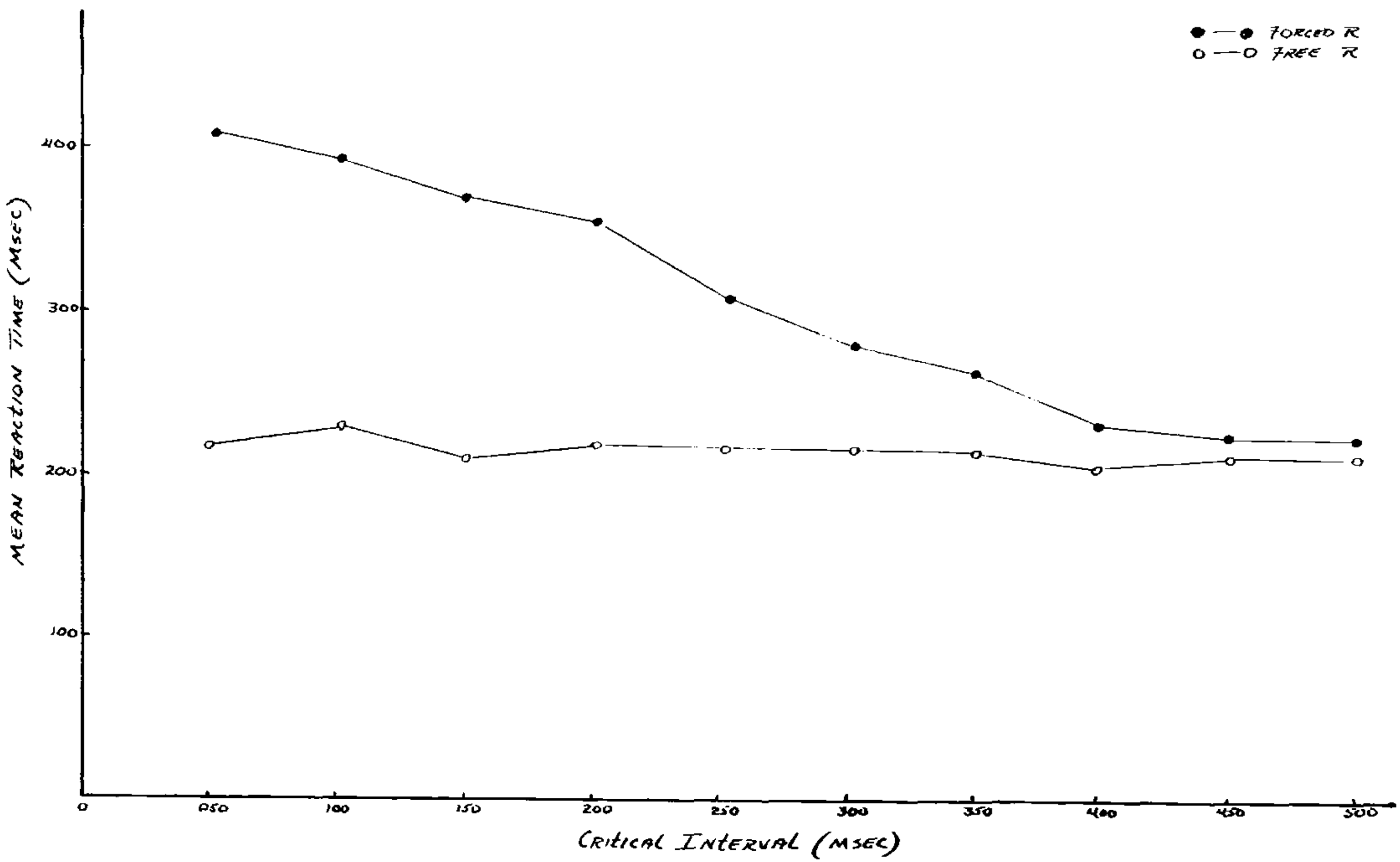


Figure 2. Mean Reaction Time as a Function of Response-Stimulus Interval

Table 6. Summary of the Newman-Keuls Mean by Mean Comparisons for the Mean Reaction Times of the Forced Response Condition

ISI	500	450	400	350	300	250	200	150	100	050
Mean RT	234	234	243	276	286	311	356	360	395	404
500	-			*	*	*	*	*	*	*
450		-		*	*	*	*	*	*	*
400			-	*	*	*	*	*	*	*
350				-		*	*	*	*	*
300					-		*	*	*	*
250						-	*	*	*	*
200							-		*	*
150								-	*	*
100									-	

(* -- Significance at $P < 0.01$)

The overall results of the data analysis enable one to reject the null hypothesis of no refractoriness due to stimulus interference with response emission. The data also tend to support a single channel explanation of sensory-motor performance.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Research Conclusions

The results of the analyses of the two stimulus presentation gave evidence for a single channel theory of information processing. Despite the fact that the sequence of stimulus presentation was unidirectional, the latency of reaction to the second of two stimuli was demonstrated. Thus, despite high event certainty, the existence of the psychological refractory period was substantiated.

The finding of equivalence of the two response and the one response cases was surprising in light of previous studies (kay and Weiss, 1961; Nickerson, 1965b). One conclusion that may be drawn from the present data is that the initial response in the two response case may become almost reflexive due to the constancy of the foreperiods. The response could be made some fixed time after the alerting signal. Under those conditions, one would not expect a differential between the one and two response case since only one reactive response would be involved.

The refractory period as defined as less than 300 msec is consistent with studies which utilized a similar experimental paradigm (Davis, 1956, 1957, 1959).

The increase in reaction latency at an interstimulus interval of 250 msec would be predicted for the two response case by the sensory-motor theory of Welford (1952). This theory hypothesizes that proprioceptive feedback can seize control of the central mechanisms similar to a stimulus input. The model theorizes a feedback time of approximately 150 msec (Welford, 1952, p. 5). If one substitutes in the Davis formula (1956, p. 27),

$$RT_2 = RT_1 + RT_n + F_b - I$$

where: RT_n = Normal reaction time.

RT_1 = Reaction time to the first stimulus.

RT_2 = Reaction time to the second stimulus.

F_b = Proprioceptive feedback.

I = Interstimulus interval.

and solves for the interstimulus interval (I), the result is a value of 260 msec, which corresponds to the interstimulus interval of 250 msec at which the increase was empirically observed. This finding is post hoc, but suggestive.

More difficult to explain is the similar increase in the curve at an interstimulus interval of 250 msec for the two stimulus, one response group. Interoceptive feedback from an implicit response tendency is a speculative conclusion.

The finding of no refractory trend for the results of those subjects who responded to a stimulus no earlier than 50 msec after the completion of a response was consistent with the results of Davis (1965). This finding concurs with all theories of the psychological refractory period, except the expectancy theory which would predict reaction time to be a function of the statistical distribution of the interstimulus intervals (Elithorn, 1961; Elithorn and Lawrence, 1955). The lack of response latency can also be accounted for in terms of interstimulus intervals. The subject characteristically waited 650 msec before emitting a response. If the alerting signal is considered as the first stimulus of the sequence, the minimum interstimulus interval is 700 msec (emission time plus the minimum critical interval). This value exceeds even the refractory period for continuous tracking (500 msec).

The finding of refractoriness in response for the group which was required to emit a response prior to making a reactive response suggests support for a single channel hypothesis of human functioning, within the limits of generality allowed by the sample. This finding is more pronounced than the data indicate, for it was noted on subsequent examination that the subjects typically emitted their initial responses at approximately 600 msec. Thus, the presented critical intervals were 50 msec longer than expected and the curves offset to the right, making the effect even more persistent. However, the results are not unequivocal for the revised theory of Welford (1959) would predict that reaction time would be decreased as the stimulus arrived nearer the point of response formation. The rationale for this prediction is that of the grouping phenomenon. The present results do not support this prediction since the reaction latency increased with decreases in critical interval, i.e., the stimulus was presented nearer the point of response formation.

The results can be better explained by the single channel corollary of response competition. This view states that the more similar the responses, the more likely there are to be increased reaction latencies due to response interference (Smith, 1967). In the present experiment the responses were qualitatively equivalent. Therefore, the possibility of response competition was maximized.

One final conclusion deals with the differences in the limits of the psychological refractory period as a function of the task. It was noted that the forced response condition resulted in slower reaction times at all intervals, as well as significantly greater variability. The reaction time is a relatively stable phenomenon (Teichner, 1954), thus the variability is itself an important finding. The greater range of response refractoriness can be explained in terms of feedback from the emitted response. The fact that it is emitted later in the critical interval than in the two stimulus case discussed above would account for the increased refractory period.

Recommendations for Future Research

Based on the results and conclusions of the present experiment, other areas in the stimulus-response sequence are suggested for future study.

The possibility of response feedback and the suggestion of interference with subsequent responses has not been studied at any length. The findings expressed above indicate that this should be explored using a response of greater duration. A longer response would permit quantitative analysis of the interference process.

The area of response competition has received little attention. It could be studied by the comparison of two responses in the same sense modality versus responses in two modalities. The latter condition would require correction for differential cortical arrival times.

Thus, the study of the psychological refractory period has by no means been exhausted. There remain many problems unanswered in this critical area of human sensory-motor performance.

APPENDIX A

APPARATUS CONFIGURATIONS

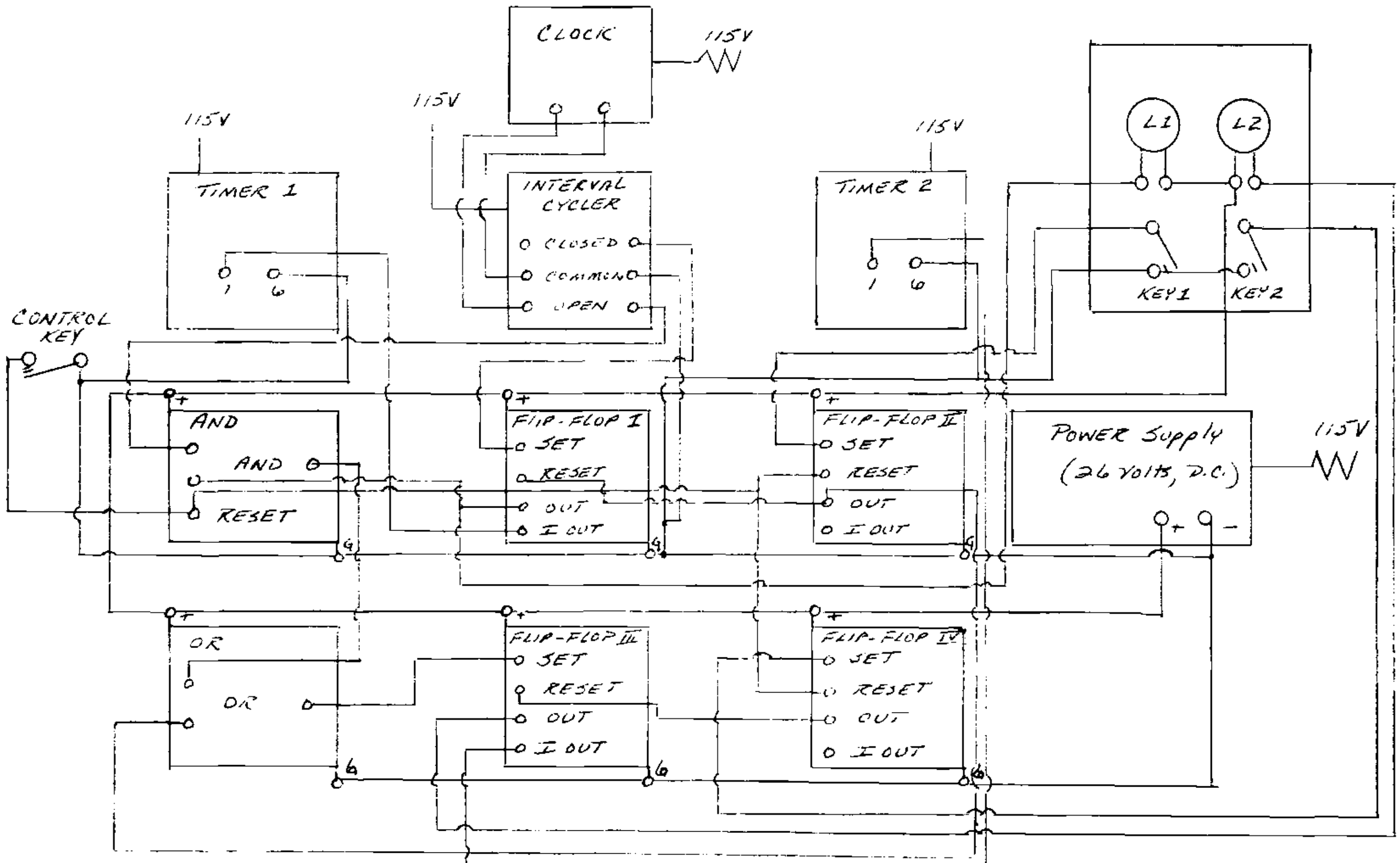


Figure 3. Basic Wiring Diagram, Two Stimuli Presented and Two Responses Recorded

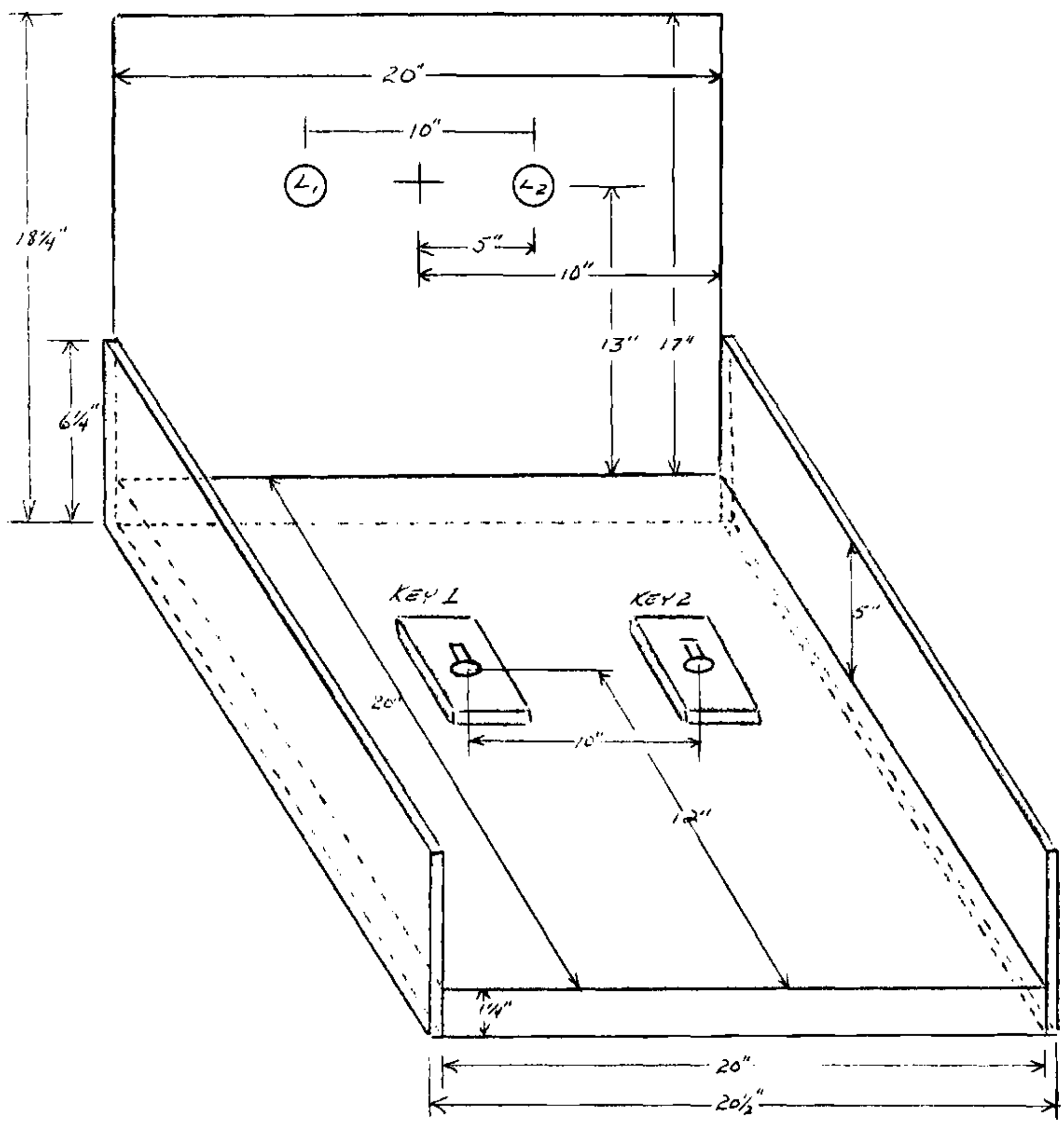


Figure 4. Stimulus and Response Apparatus

Table 7. Alterations Necessary in the Basic Wiring Diagram to Present Alternative Conditions

Experimental Paradigm	Apparatus Alterations
Two Stimuli--One Response	(1) Disconnect key one at set on flip-flop II. (2) Connect set on flip-flop II to set on flip-flop IV.
Forced Response	(1) Disconnect light one at output on flip-flop I.
Freely Emitted Response	(1) Disconnect light one at output on flip-flop I. (2) Disconnect AND gate input at output on flip-flop I. (3) Connect AND gate input at output on flip-flop II (4) Disconnect flip-flop II output at input on OR gate. (5) Set Channel B to zero on interval cycler.
Simple Reaction Time	(1) Connect set on flip-flop II to set on flip-flop IV. (2) Disconnect light at output on flip-flop I or flip-flop III. (3) Set Channel A and Channel B to zero on interval cycler.

APPENDIX B

GENERAL INSTRUCTIONS FOR ALL SUBJECTS

This experiment deals with reaction to visual signals.

You are to sit with your arms extended and index fingers resting on the telegraph keys. Look at the attention point between the lights. Are you comfortable? (Adjust the apparatus until the subject is comfortably positioned.)

In this first part of the experiment, you are to respond as rapidly as you can by depressing the key corresponding to a light as soon as it is lit. The left key corresponds to the left light and the right key corresponds to right light. Each presentation will be preceded by my saying "ready." Only one light will occur on each trial and it may appear in either position.

Are there any questions?

APPENDIX C

INSTRUCTIONS FOR SUBJECTS IN THE TWO STIMULUS, TWO RESPONSE GROUP

In the next part of the experiment, you are again to place your index fingers on the telegraph keys and look at the attention point between the two lights.

You are to respond as rapidly as you can by depressing the key corresponding to a light as soon as it is lit. The left key corresponds to the left light and the right key corresponds to the right light.

To start each trial, I will say "ready." Both lights will be turned on during each trial and you are to respond to both.

Are there any questons?

APPENDIX D

INSTRUCTIONS FOR SUBJECTS IN THE TWO STIMULUS, ONE RESPONSE GROUP

In the next part of the experiment, you are again to place your index fingers on the telegraph keys and look at the attention point between the two lights.

You are to respond as rapidly as you can by depressing the key corresponding to the second light to be lit as soon as it is turned on. The left key corresponds to the left light and the right key corresponds to the right light.

I will start each trial by saying "ready." Both lights will be turned on each trial and you are to respond only to the second light.

Are there any questions?

APPENDIX E

INSTRUCTIONS FOR SUBJECTS IN THE FORCED RESPONSE GROUP

In the next part of the experiment you are again to place your index fingers on the telegraph keys.

To start each trial I will say "ready." When you *are* ready, you are to make a response by depressing the left key. When the right light is turned on, you are to respond to it as rapidly as you can by depressing the right key. However, if the right light is turned on before you have depressed the left key, the left key must still be depressed before the right key. The left light will not be turned on at all during this part of the experiment.

To repeat, the sequence will be initiated by my saying "ready." You are to depress the left key when you are ready. You are to respond as rapidly as you can to the right light whenever it is turned on. However, the left key press must always precede the right key press.

Are there any questions?

APPENDIX F

INSTRUCTIONS FOR SUBJECTS IN THE FREELY EMITTED RESPONSE GROUP

In the next part of the experiment you are again to place your index fingers on the telegraph keys.

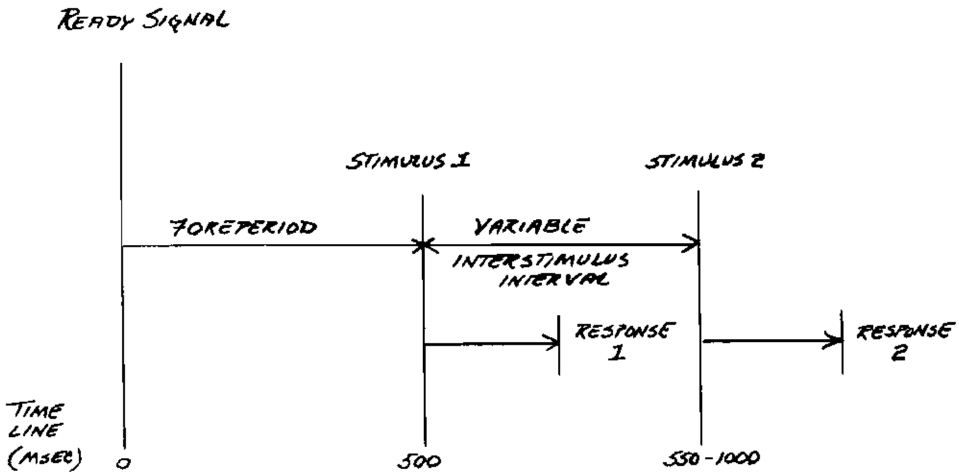
To start each trial I will say "ready." When you *are* ready, you are to make a response by depressing the left key. When the right light is turned on, you are to respond to it as rapidly as you can by depressing the right key. The left light will not be turned on at all during this part of the experiment.

To repeat, the sequence will be initiated by my saying "ready." You are to press the left key when you are ready. You are to respond as rapidly as you can to the right light whenever it is turned on.

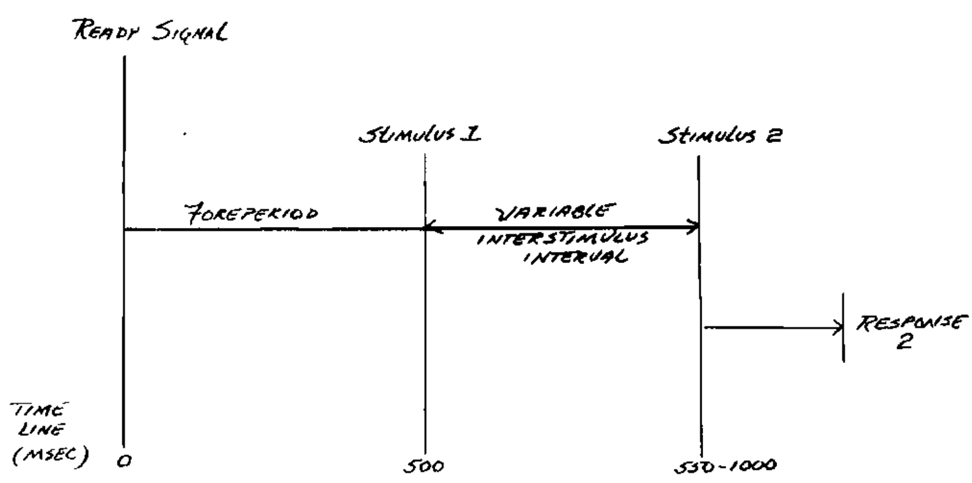
Are there any questions?

APPENDIX G

EXPERIMENTAL PARADIGMS

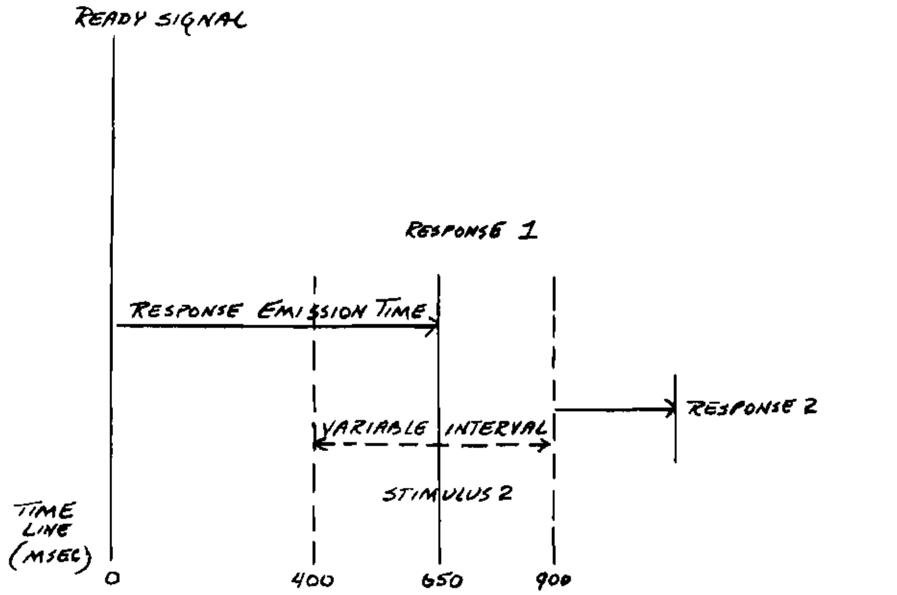


a) Two Stimuli — Two Response

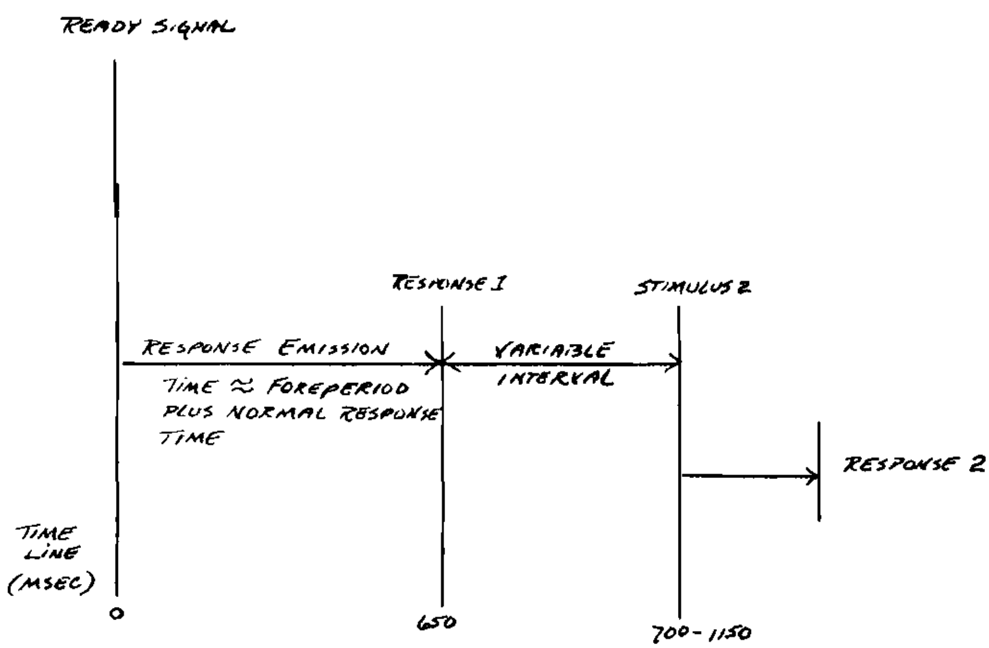


b) Two Stimuli — ONE RESPONSE

Figure 5. Time Relations for the Two Stimuli Conditions



a) FORCED RESPONSE (R_1 MUST ALWAYS PRECEDE R_2)



b) FREELY EMITTED RESPONSE

Figure 6. Time Relations for the Emitted Response Conditions

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